IOP Publishing Plasma Physics and Controlled Fusion
Plasma Phys. Control. Fusion 63 (2021) 125031 (14pp) https://doi.org/10.1088/1361-6587/ac2af8

Self-consistent simulation of resistive kink instabilities with runaway electrons

Chang Liu[1,*], Chen Zhao[1], Stephen C Jardin[1], Nathaniel M Ferraro[1], Carlos Paz-Soldan[2], Yueqiang Liu[3] and Brendan C Lyons[3]

[1] Princeton Plasma Physics Laboratory, Princeton, NJ, United States of America
[2] Columbia University, New York, NY, United States of America
[3] General Atomics, San Diego, CA, United States of America

E-mail: cliu@pppl.gov

Received 21 April 2021, revised 29 July 2021
Accepted for publication 28 September 2021
Published 15 November 2021

Abstract
A new fluid model for runaway electron (RE) simulation based on fluid description is introduced and implemented in the magnetohydrodynamics (MHD) code M3D-C1, which includes self-consistent interactions between plasma and REs. The model utilizes the method of characteristics to solve the continuity equation for the RE density with large convection speed, and uses a modified Boris algorithm for pseudo particle pushing. The model was employed to simulate MHD instabilities happening in a RE final loss event in the DIII-D tokamak. Nonlinear simulation reveals that a large fraction of REs get lost to the wall when kink instabilities are excited and form stochastic field lines in the outer region of the plasma. Plasma current converts from RE current to Ohmic current. Given the agreements with experiment on RE loss ratio and mode growing time, the simulation model provides a reliable tool to study macroscopic plasma instabilities in existence of RE current, and can be used to support future studies of RE mitigation strategies in ITER.

Keywords: disruption, MHD, runaway electron

(Some figures may appear in colour only in the online journal)

1. Introduction

Severe damage can be caused by high-energy runaway electrons (REs) generated in tokamak disruption events, which is one of the major threats to the safe operation of ITER [1]. It is predicted that large populations of REs can be generated during the current quench phase through knock-on collisions and the resulting RE avalanche [2, 3]. The current associated with REs can be several mega-ampere (MAs). It can alter the macroscopic magnetohydrodynamics (MHD) stability conditions and thus plays an important role in the disruption process. Several present-day tokamaks, including DIII-D [4], JET [5], ASDEX [6], and J-TEXT [7] have been used to test RE avoidance and mitigation strategies in order to control this issue in ITER and future fusion reactors.

In recent experiments on DIII-D [8] and JET [9] with large RE current generation, significant MHD instabilities are observed in the RE current plateau phase after the initial disruption, which leads to the loss of most REs within tens of microseconds [10]. These experiments indicate the importance of MHD instabilities in a successful RE mitigation. In the experiments, high-Z impurities are expelled via deuterium injection, which also lowers the plasma density [11]. The interaction between MHD instabilities and RE current has been studied before theoretically with both analytical theory and numerical simulations [12–16]. In the simulation, a fluid description of REs is used to simplify the calculation, in which RE current is calculated from RE density, and the feedback of RE current to MHD is included in the generalized Ohm's

* Author to whom any correspondence should be addressed.

